OPEN-FILE REPORT 97-20

SEISMIC HAZARD EVALUATION OF THE TUSTIN 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

Revised 2001

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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CONTENTS

ILLUSTRATIONS

PREFACE

The Tustin quadrangle was issued as an Official Seismic Hazard Zone Map April 15, 1998. Since that time, CDMG has completed zoning the El Toro quadrangle to the east and Orange county and Irvine have submitted 172 geotechnical reports as required by the SHMA. Because this is a rapidly developing area, we are issuing a REVISED OFFICIAL Tustin zone map in order to provide the most current information for local planning and construction permitting.

The liquefaction analysis done while mapping the El Toro quadrangle to the east indicated: (1) a high ground water table in the sandy sediments along the San Diego Creek channel which enters the southeast corner of the quadrangle and, (2) the high terrace material in the northeast section of the quadrangle are relatively clay-rich with deep groundwater levels. For these reasons, a liquefaction zone was added along the San Diego stream channel and a zoned terrace area was deleted in the northeast quarter of the quadrangle (see map). New information was examined from geologic reports submitted by the city and no further modification of the zoning is indicated. We are currently reviewing reports triggered inside the zone to determine compliance with the Act, mitigation techniques, and program effectiveness.

The State Legislature passed the Seismic Hazards Mapping Act in 1990 because of the increasing public concern about the potential for destructive earthquakes in California,. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The Board also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and is adopted by the State Mining Board.

The Official Seismic Hazard Zone Maps, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Evaluation Reports are not available through BPS Reprographic Services.**

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Seismic hazard evaluation reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Tustin 7.5-Minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Tustin 7.5-Minute Quadrangle, Orange County, California

By
Richard B. Greenwood

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Tustin 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within the upper 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Tustin Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Tustin Quadrangle covers an area of about 60 square miles of Orange County land near the southeastern edge of the Los Angeles Basin. The City of Irvine lies near the center of the quadrangle. In the northern two-thirds of the quadrangle, portions of the cities of Santa Ana, Tustin, Costa Mesa, and Newport Beach occupy the nearly flat-lying area of the Tustin Plain. The southern one-third of the quadrangle encompasses the San Joaquin Hills. Streams that flow out of the San Joaquin Hills drain mainly toward the north. The predominant drainage pattern across the Tustin Plain is from northeast to southwest toward Newport Bay.

The study area lies within the northwesternmost part of the Santa Ana Mountains in the Peninsular Ranges geomorphic province of southern California. The basin area consists of a sequence of flat-lying basin sediments and Holocene or modern fluvial deposits. The San Joaquin Hills are bordered on the north by dissected terraces that merge with the valley floor deposits to the north.

Access to the Tustin Quadrangle is provided by the Newport Freeway (State Highway 55), Santa Ana Freeway (Interstate Highway 5) and San Diego Freeway (Interstate Highway 405) and by numerous boulevards and main streets. A new highway, the San Joaquin Transportation Corridor has recently been constructed along the southern portion of the quadrangle. Residential and commercial developments and military installations cover the valley floor north of the San Joaquin Hills. New residential development over the past twenty years has taken place mainly on the Tustin Plain and along the lower slopes of the nearby hills.

GEOLOGIC CONDITIONS

Surface Geology

The geologic map for the Tustin Quadrangle was digitized by DMG from 1:24,000-scale mapping (Vedder and others, 1957) in the north half and 1:12,000-scale mapping (Miller and Tan, 1976) in the south half of the quadrangle. Geologic mapping of the Quaternary units in the lowland areas and unit designations were compiled by the Southern California Areal Mapping Project [SCAMP] and stratigraphic nomenclature was revised to follow the format developed by SCAMP (Morton and Kennedy, 1989). The U.S. Geological Survey (Schoellhamer and others, 1981) described the geologic units in the northern Santa Ana Mountains. The Quaternary geologic map of the Tustin Quadrangle is reproduced as Plate 1.1.

The oldest Quaternary geologic unit mapped in the Tustin Quadrangle is the late Pleistocene marine terrace deposits (Qvom), which are predominantly marine silty sand and gravel deposits exposed in the San Joaquin Hills in the southwestern corner of the quadrangle. Older alluvium (Qvoa) and older fan deposits (Qvof) locally overlie these deposits.

Quaternary deposits of older alluvium flank the lower slopes of the San Joaquin Hills and the Santa Ana Mountains and are inferred to lie beneath the Tustin Plain. The deposits associated with the Santa Ana River, lower Santiago Creek, San Diego Creek and Peters Creek include late Pleistocene (?) to Holocene floodplain and stream terrace deposits (Qvoma, Qvoa, Qvof, Qyf, Qya, Qywa). These deposits consist of unconsolidated to poorly consolidated, non-marine mixtures of sand, silt, and gravel. The only units mapped in this quadrangle as artificial fill (af) are earth-filled dam embankments and highway-related engineered fills.

Subsurface Geology and Geotechnical Characteristics

The geologic units described above were primarily compiled by the Southern California Areal Mapping Project (SCAMP) from early soil survey maps (Eckmann and others, 1916). Subsurface properties were described in over 504 borehole logs in the study area. Subsurface data used for this study include the database compiled by Sprotte and others (1980) for previous ground response studies. Additional data collected for this study came from DMG files of seismic reports for hospital and school sites and the Orange County Health Care Agency. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable, however, due to the use of non-standard equipment and incomplete reporting of procedures.

Data from previous databases and additional borehole logs were entered into the DMG GIS database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections from the borehole logs, using the GIS, enabled the correlation of soil types from one borehole to another and the outlining of areas of similar subsurface units.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized, but give the most commonly encountered characteristics of the units (see Table 1.1).

Pleistocene marine terrace deposits (Qvoma and Qvoma+aa)

Pleistocene marine terrace deposits (Qvoma and Qvoma+aa) make up much of the terraces underlying the northern slopes of the San Joaquin Hills, in the southwestern part of the Tustin Quadrangle. The deposits generally consist of dense to very dense sand and silty sand with local looser fine sands and silty sand layers.

Older fan deposits (Qvof)

Late Pleistocene (?) older fan deposits were mapped by Miller and Tan (1976) in the Santiago Creek drainage. These deposits are dissected by younger fan deposits and typically consist of dense to very dense sand and gravel with interbedded sand and silty sand.

Older alluvial deposits (Qvoa)

Late Pleistocene (?) older alluvial deposits were mapped by Miller and Tan (1976) in the Santiago Creek. These deposits typically include dense to very dense sand and gravel with interbedded silty sand and sand.

Younger fan deposits (Qyf)

Younger fan deposits, which include floodplain deposits on the compiled geologic map from SCAMP, generally consist of unconsolidated sand, sandy silt, and silt of Santa Ana River, Santiago Creek, and Peters Creek origin.

Younger alluvial deposits (Qya)

Younger alluvial deposits in drainages east of Newport Bay, in the southwest corner of the Tustin Quadrangle, generally consist of loose silty sand, sand, and minor amounts of gravel.

Active wash deposits (Qywa)

Active wash deposits were identified by Miller and Tan (1976) within the active drainages of the Bonita Creek and other minor drainages on the northern slope of the San Joaquin Hills. They generally consist of wet, loose, sands and gravelly sands.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qywa, active wash deposits	Sand, gravelly sand	loose	High
Qyf, younger fan deposits	Sand & gravel, sand, silty sand	loose	High
Qya, younger alluvium	Silty sand, sand, minor gravel	loose	High
Qvof, old fan deposits	Sand & gravel and silty sand	dense-very dense	Low
Qvoa, old alluvium	Silty sand and sand & gravel	dense-very dense	Low
Qvoma, marine terraces	Sand & silty sand	dense-very dense	Low

Table 1.1. General geotechnical characteristics and liquefaction susceptibility of younger Quaternary units.

GROUND-WATER CONDITIONS

Liquefaction hazard mapping focuses on areas historically characterized by ground-water depths of 40 feet or less. Accordingly, ground-water conditions were investigated in the Tustin Quadrangle to evaluate the depth to saturated sediments. Saturated conditions reduce the normal effective stress acting on loose, near-surface sandy deposits, thereby increasing the likelihood of liquefaction (Youd, 1973). The evaluation was based on first water levels encountered in geotechnical borings and selected water wells. The depths to first encountered water free of piezometric influences were plotted and contoured onto a map showing depths to historically shallowest ground water (Plate 1.2). This map was digitized and used for the liquefaction analysis.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Tustin Quadrangle, peak accelerations of 0.35 g to 0.40 g resulting from an earthquake of magnitude 6.8 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. These properties and conditions are correlated with geologic age and environment of deposition. With increasing age of a deposit, relative density may increase through cementation of the particles or the increase in thickness of the overburden sediments. Grain size characteristics of a soil also influence susceptibility to liquefaction. Sands are more susceptible than silts or gravels, although silts of low plasticity are treated as liquefiable in this investigation. Cohesive soils are generally not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in lower liquefaction susceptibility generally result in higher penetration resistances to the soil sampler. Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). Therefore, blow count or cone penetrometer values are a useful indicator of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (more likely to liquefy). Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense.

DMG’s map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG’s qualitative susceptible soil inventory is outlined below and summarized on Table 1.1.

Pleistocene marine terrace deposits (Qvoma and Qvoma+aa)

Pleistocene marine terrace deposits (Qvoma and Qvoma+aa) make up much of the terraces underlying the northern slopes of the San Joaquin Hills, in the southwestern part of the Tustin Quadrangle. The deposits generally consist of dense to very dense sand and silty sand with local looser fine sands and silty sand layers. These softer marine terraces were not zoned as they exceed age restrictions (older than11, 000 to 15,000 years) defined by zoning criteria.

Older fan deposits (Qvof)

Late Pleistocene (?) older fan deposits were mapped by Miller and Tan (1976) in the Santiago Creek drainage. These deposits are dissected by younger fan deposits and typically consist of dense to very dense sand and gravel with interbedded sand and silty sand. Liquefaction susceptibility of this unit is low.

Older alluvial deposits (Qvoa)

Late Pleistocene (?) older alluvial deposits were mapped by Miller and Tan (1976) in the Santiago Creek. These deposits typically include dense to very dense sand and gravel with interbedded silty sand and sand. Liquefaction susceptibility of this unit is low.

Younger fan deposits (Qyf)

Younger fan deposits, as compiled by SCAMP, include floodplain deposits. They generally consist of unconsolidated sand, sandy silt, and silt of Santa Ana River, Santiago Creek, and Peters Creek origin. Qyf consists of sand, sandy silt, and silt, which is loose to moderately dense and is, commonly, saturated. Where saturated, liquefaction susceptibility of this unit is generally high.

Younger alluvial deposits (Qya)

Younger alluvial deposits, as mapped by SCAMP, occur in drainages east of Newport Bay, in the southwestern corner of the Tustin Quadrangle. They generally consist of loose silty sand, sand, and minor amounts of gravel. Where saturated, liquefaction susceptibility of this unit is generally high.

Active wash deposits (Qywa)

Miller and Tan (1976) identified active wash deposits within the active drainages of Bonita Creek and other minor drainages on the northern slope of the San Joaquin Hills. The deposits generally consist of loose sand and gravelly sand layers. Where saturated, liquefaction susceptibility of this unit is generally high.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the “trigger” for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil are evaluated in order to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Of the 504 geotechnical borehole logs reviewed in this study (Plate 1.2), 175 include blow-count data from SPT’s or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Tustin Quadrangle is summarized below.

Areas of Past Liquefaction

Liquefaction is not documented to have occurred within the Tustin Quadrangle.

Areas with Sufficient Existing Geotechnical Data

The older alluvium and fan deposits exposed in the Tustin Quadrangle (Qvof, Qvoa,) have a dense consistency and deep ground water where encountered in boreholes in of much of the area underlain by these units. Accordingly, these geologic units have not been included in a liquefaction hazard zone.

Younger fan and alluvial deposits (Qyf and Qya) commonly have layers of loose silty sand or sand. Where these deposits are saturated, they are included in a liquefaction hazard zone.

Active wash deposits (Qywa) are typically loose saturated sand. They are included in liquefaction hazard zones.

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REFERENCES

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Eckmann E.C., Strahorn, A.T., Holmes, L.C. and Guernsey, J.E., 1916, Soils map of the Anaheim area, California: United States Department of Agriculture, Bureau of Soils, in cooperation with University of California, Agricultural Experiment Station, scale 1:62,500.

Greenwood, R.B. and Morton, D.M., 1990, Geologic map of the Santa Ana 1:100,000 Quadrangle, California: California Division of Mines and Geology Open-File Report 91-17, 3 plates.

Miller, R.V. and Tan, S.S., 1976, Geology and engineering aspects of the south half of the Tustin Quadrangle, Orange County, California: California Department of Conservation, Division of Mines and Geology Special Report 126, 28 p., map scale 1: 12,000.

Morton, D.M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series: The Santa Ana Quadrangle, The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, affected by the 17 January 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Schoellhamer, J.E., Vedder, R.G, Yerkes, R.F. and Kinney, D.M., 1981, Geology of the northern Santa Ana Mountains, California: U.S. Geological Survey Professional Paper 420-D, 70 p., map scale 1:24,000.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, H.B., Tokimatsu, Kohji, Harder, L.F. and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Sprotte, E.C., Fuller, D.R., Greenwood, R.B., Mumm, H.A., Real, C.R. and Sherburne, R.W., 1980, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 80-19LA, Map Number 3, 4 plates.

Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, *in* Ziony, J. I., *editor*, Evaluating earthquake hazards in the Los Angeles Region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-125.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region -- An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.

Vedder, J.G., Yerkes, R.F. and Schoellhamer, J.E., 1957, Geologic map of the San Joaquin Hills-San Juan Capistrano area, Orange County, California: U.S. Geological Survey Oil and Gas Inv. Map OM-193, scale 1:24,000.

Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Tustin 7.5-Minute Quadrangle, Orange County, California

By
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Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Tustin 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, and loose soils, and on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Tustin Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Seismic Hazards Mapping Act (Public Resources Code, Chapter 7.8, Division 2). As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Tustin Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Tustin Quadrangle covers an area of about 60 square miles of Orange County land near the southeastern edge of the Los Angeles Basin. The City of Irvine lies near the center of the quadrangle. In the northern two-thirds of the quadrangle, portions of the cities of Santa Ana, Tustin, Costa Mesa, and Newport Beach occupy the nearly flat-lying area of the Tustin Plain. The southern one-third of the quadrangle encompasses the San Joaquin Hills. Streams that flow out of the San Joaquin Hills drain mainly toward the north. The predominant drainage pattern across the Tustin Plain is from northeast to southwest toward Newport Bay.

The study area lies within the northwesternmost part of the Santa Ana Mountains in the Peninsular Ranges geomorphic province of southern California. The basin area consists of a sequence of flat-lying basin sediments and Holocene or modern fluvial deposits. The San Joaquin Hills are bordered on the north by dissected terraces that merge with the valley floor deposits to the north.

Access to the Tustin Quadrangle is provided by the Newport Freeway (State Highway 55), Santa Ana Freeway (Interstate Highway 5) and San Diego Freeway (Interstate Highway 405) and by numerous boulevards and main streets. A new highway, the San Joaquin Transportation Corridor has recently been constructed along the southern portion of the quadrangle providing access to the City of Laguna Beach and other south coastal areas.

Residential and commercial developments and military installations cover the valley floor north of the San Joaquin Hills. New residential development over the past twenty years has taken place mainly on the Tustin Plain and along the lower slopes of the nearby hills. Most of more recent residential developments in the quadrangle have been in the upland area of the San Joaquin Hills. These developments have typically been built as large projects using substantial hillslope grading and drainage modification prior to construction.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

The geologic map for the Tustin Quadrangle was digitized by DMG from 1:24,000-scale mapping (Vedder and others, 1957) in the north half and 1:12,000-scale mapping (Miller and Tan, 1976) in the south half of the quadrangle. Geologic mapping of the Quaternary units in the lowland areas and unit designations were compiled by the Southern California Areal Mapping Project (1995). The mapping was modified during this project to reflect field observations and the most recent mapping in the area. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of slope failures was noted. The geologic unit descriptions below are taken mainly from the U.S. Geological Survey (Vedder and others, 1957) mapping done in this area.

The oldest geologic units exposed in the Tustin Quadrangle are Tertiary rocks of the Silverado (Tsi) and Santiago (Tsa) formations. Both these formations consist of nonmarine to partly marine beds of sandstone, siltstone, clay and conglomerate. The Santiago Formation is conformably overlain by the Sespe Formation (Ts) of late Eocene to early Miocene age and the Vaqueros Formation (Tvv, Tvs) of early Miocene age. These formations consist of nonmarine to marine beds of sandstone, siltstone, clay and conglomerate. The Miocene Topanga Formation consists of an undifferentiated unit (Tt) and three members (Ttb, Ttlt, Ttp), which are composed of mixtures of interbedded sandstone, siltstone, clay, and conglomerate. The Capistrano, Niguel and Monterey formations (Tcs, Tn, Tm) are composed of variable beds of conglomerate, siltstone, and sandstone. Minor, unmapped diabase dikes intrude some of the bedrock units along the southern border of the map.

Quaternary deposits are located in the low valley area in the southern portion of the quadrangle. They are comprised of Holocene and upper Pleistocene alluvium and colluvium, floodplain, stream terrace deposits (Qya, Qyf, Qof, Qvo) and landslide deposits (Qls). These materials are poorly sorted and crudely layered. They consist of varying amounts of clay, silt, sand, and gravel. A more detailed discussion of the Quaternary deposits in the Tustin Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they first must be ranked based on their overall shear strength. Shear strength data for the rock units identified on the geologic map were obtained mainly from the consulting firm of Leighton and Associates (see Appendix A). Shear strength data were also obtained from geotechnical sections of Environmental Impact Reports on file at the Division of Mines and Geology's Sacramento office. The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above source were compiled for each mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average ϕ) and lithologic character. Geologic formations that have little or no shear test information were added to existing groups on the basis of lithologic and stratigraphic similarities. The rock strength data do not indicate that there was a strong difference between the fine-grained and coarse-grained lithologies within formations. The results of the grouping of geologic materials in the Tustin Quadrangle are in Tables 2.1 and 2.2.

Structural Geology

Because of the homogeneous character of bedrock units in the Tustin Quadrangle, it was determined that the underlying geologic structure does not have a significant impact on slope stability of these rock units. Although the layered sedimentary rocks have relatively shallow bedding dips that may contribute to slope instability, there is a greater difference in material strength between formations than internally within formations. It was, therefore, determined that

TUSTIN QUADRANGLE
SHEAR STRENGTH GROUPINGS

	Formation Name	Number Tests	Mean phi value	Group Phi Mean/Median (deg)	Group C Mean/Median (psf)	No Data: Similar Lithology	Phi Values Ued in Stability Analyses
GROUP 1	Tm	16	33.8	33.8/36.5	731/480	Tsa, Tsi	**35**
GROUP 2	Tn Tvs	3 6	33.8 33.7	33.7/34	278/200	Tcs, Td, Ts, Tt Ttb, Ttlt, Ttp, Tv	**32**
GROUP 3	Qyf Qya Qof	11 25 1	25 28.2 28	27.6/28	317/200	Qvo	**27**
GROUP 4	Qls	14	12.4	12.4/11.5	747/775		**12**

Table 2.1. Summary of the shear strength statistics for the Tustin Quadrangle.

SHEAR STRENGTH GROUPS FOR THE
TUSTIN QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4
Tm	Tn	Qya	Qls
Tsa	Tvs	Qyf	
Tsi	Tcs	Qof	
	Td	Qvo	
	Ts		
	Tt		
	Ttb		
	Ttlt		
	Ttp		
	Tv		

Table 2.2. Summary of the shear strength groups for the Tustin Quadrangle.

adverse bedding dips are not a significant factor in the material strength and no attempt was made to identify adverse bedding conditions in the Tustin Quadrangle.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. DMG geologists compiled the existing landslides in the Tustin Quadrangle from published landslide maps (Miller and Tan, 1976). Then, by combining field observations with analysis of aerial photos from the Whittier College-Fairchild Collection of 1927 (also see Air Photos in References) and interpretation of landforms, all landslides on the compiled landslide map were either verified, re-mapped, or deleted during preparation of the landslide inventory map.

The completed hand-drawn landslide map was scanned, digitized, and the database was attributed with information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Only those landslides classified in the DMG inventory as definite or probable were incorporated into the hazard-evaluation process. During final review of the zone maps, landslides that are mapped totally within graded areas have been deleted. Landslides with mapped boundaries that extend outside the footprint of the grading are considered intact and capable of failure. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Tustin Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8 to 6.9
Modal Distance:	8.0 to 24 km
PGA:	0.30 to 0.37 g

The strong-motion record selected was the Channel 3 (north 35 degrees east horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a PGA of 0.59 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232g. These yield acceleration values were then used as earthquake-induced landslide susceptibility criteria in the stability analyses.

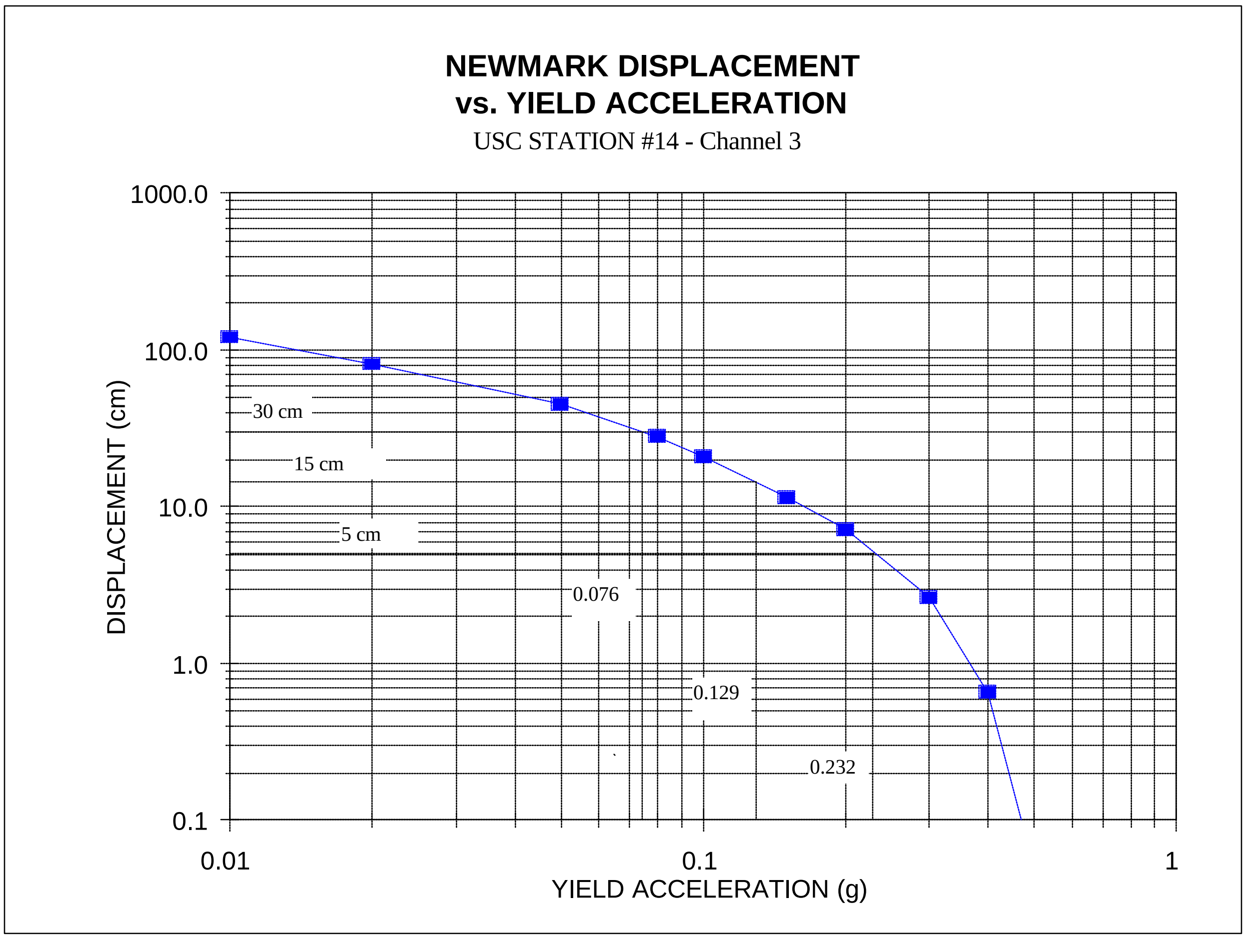

Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station # 14 strong-motion record from the 17 January 1994 Northridge, California Earthquake.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Tustin Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the U.S. Geological Survey. This DEM has a 10-m horizontal resolution and a 7.5-m vertical accuracy (USGS, 1993) and was prepared from topographic contours based on 1963 photographs. A program that adds a pixel to the edges of the DEM was run twice to avoid the loss of data at the quadrangle edges when the slope calculations were performed.

To update the terrain data, areas that have have undergone large-scale grading since 1963 as part of residential development were identified (see Plate 2.1) on 1:40,000-scale aerial photography flown in 1994 and 1995 (NAPP, 1994). Terrain data for this area were produced by scanning and rectifying diapositives made from the photography. Using this stereo-rectified image, DMG manually digitized the terrain to produce accurate and up-to-date topography for the mass graded area. This corrected terrain data was digitally merged with the USGS DEM.} Plate 2.1 shows the area where topography is updated.

Slope-gradient maps were made from both sets of DEM's using a third-order finite-difference center-weighted algorithm (Horn, 1981). The slope-gradient map was used in conjunction with the geologic strength map to prepare the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.076g, expected displacements could be greater than 30 cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.076 and 0.129g a MODERATE (M on Table 2.3) potential was assigned, between 0.129 and 0.232 a LOW (L on

Table 2.3) potential was assigned, and if a_y were greater than 0.232g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

TUSTIN QUADRANGLE
HAZARD POTENTIAL MATRIX

SLOPE CATEGORY

Geologic Material Strength Group	Mean Phi	I	II	III	IV	V	VI	VII	VIII	IX	
		0-13	**14-26**	**27-37**	**38-42**	**43-44**	**45-48**	**49-53**	**54-61**	**>61**	(percent)
		0-7	8-14	15-20	21-23	24-25	26-27	27-28	28-31	>32	(degrees)
1	**35**	VL	VL	VL	VL	VL	L	L	M	H	
2	**32**	VL	VL	VL	L	L	L	M	H	H	
3	**27**	VL	VL	L	M	H	H	H	H	H	
4	**12**	L-M	H	H	H	H	H	H	H	H	

Table 2.3. Hazard potential matrix for earthquake-induced landslides in the Tustin Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (1996). Under those criteria, earthquake-induced landslide zones are areas meeting one or both of the following:

1. Areas identified as having experienced landslide movement in the past (including all mappable landslide deposits and source areas), and, where possible, areas known to have experienced earthquake-induced landsliding during historic earthquakes.

2. Areas where geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, although no definitive earthquake-induced landslides are known to exist in the Tustin Quadrangle, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic material strength group 4 (mapped landslides) is always included in the zone: strength group 3 is in the zone for all slopes greater than 27%: strength group 2 above 38% and strength group 1 above 45%. This results in 900 acres (2%) of the land in the Tustin Quadrangle lying within the earthquake-induced landslide zone.

ACKNOWLEDGMENTS

The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Library assistance and geotechnical review were provided by Iraj Poormand and Kathy Black from Leighton and Associates. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board’s Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. Dr. Mushtaq Hussain and Dr. Riad Munjy of the Geomatrics Engineering Program in the School of Engineering and Computer Science at California State University, Fresno assisted in the soft-copy photogrammmetry production. At DMG, Siang Tan provided valuable geologic information, gained from years of field study, about the stability characteristics of the geologic units in the area. Special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their Geographic Information System operations support, to Joy Arthur for designing and plotting the graphic displays associated with the earthquake-induced landslide zone map, and Lisa Chisholm for preparing the landslide attribute tables for input into this report.

REFERENCES

California State Mining and Geology Board, 1996, Criteria for delineating earthquake-induced landslide hazard zones: Unpublished California State Mining and Geology Board document developed by the Seismic Hazards Mapping Act Advisory Committee.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, pp. 1645-1649.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark’s sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

Miller, R.V. and Tan, S.S., 1976, Geology and engineering aspects of the south half of the Tustin Quadrangle, Orange County, California: California Department of Conservation, Division of Mines and Geology Special Report 126, 28 p., map scale 1: 12,000.

NAPP, 1994, U.S. Geological Survey-National Aerial Photography Program (NAPP), flight 6862, frames 5-9, 66-71, flown 6/1/94, black and white, vertical, approximate scale 1:40,000.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, California, affected by the January 17, 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Schoellhamer, J.E., Vedder, R.G, Yerkes, R.F. and Kinney, D.M., 1981, Geology of the northern Santa Ana Mountains, California: U.S. Geological Survey Professional Paper 420-D, 70 p., map scale 1:24,000.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Areal Mapping Project, 1995, Digital geologic map of the Tustin 7.5-minute Quadrangle, unpublished, scale 1:24,000.

Trifunac, M.D., Todorovska, M.I. and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: Soil Dynamics and Earthquake Engineering, v. 13, no. 3, p. 187-196.

U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical structions, Data Users Guide 5, 48 p.

Vedder, J.G., Yerkes, R.F. and Schoellhamer, J.E., 1957, Geologic map of the San Joaquin Hills-San Juan Capistrano area, Orange County, California: U.S. Geological Survey Oil and Gas Inv. Map OM-193, scale 1:24,000.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

Orange County Planning Department, E.L. Pearson & Associates 1970 Aerial Photographs, flight 13, frames 22-32, flight 14, frames 19-29, flight 15, frames 17-28, flight 16, frames 15-25, flight 17, frames 14-24, flight 18, frames 12-23, and flight 19, frames 10-20, black and white, vertical, approximate scale 1:12,000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Leighton and Associates	70
California Department of Conservation, Division of Mines and Geology EIR files	10
Total number of tests used to characterize the unit material strengths	80

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Tustin 7.5-Minute Quadrangle, Orange County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

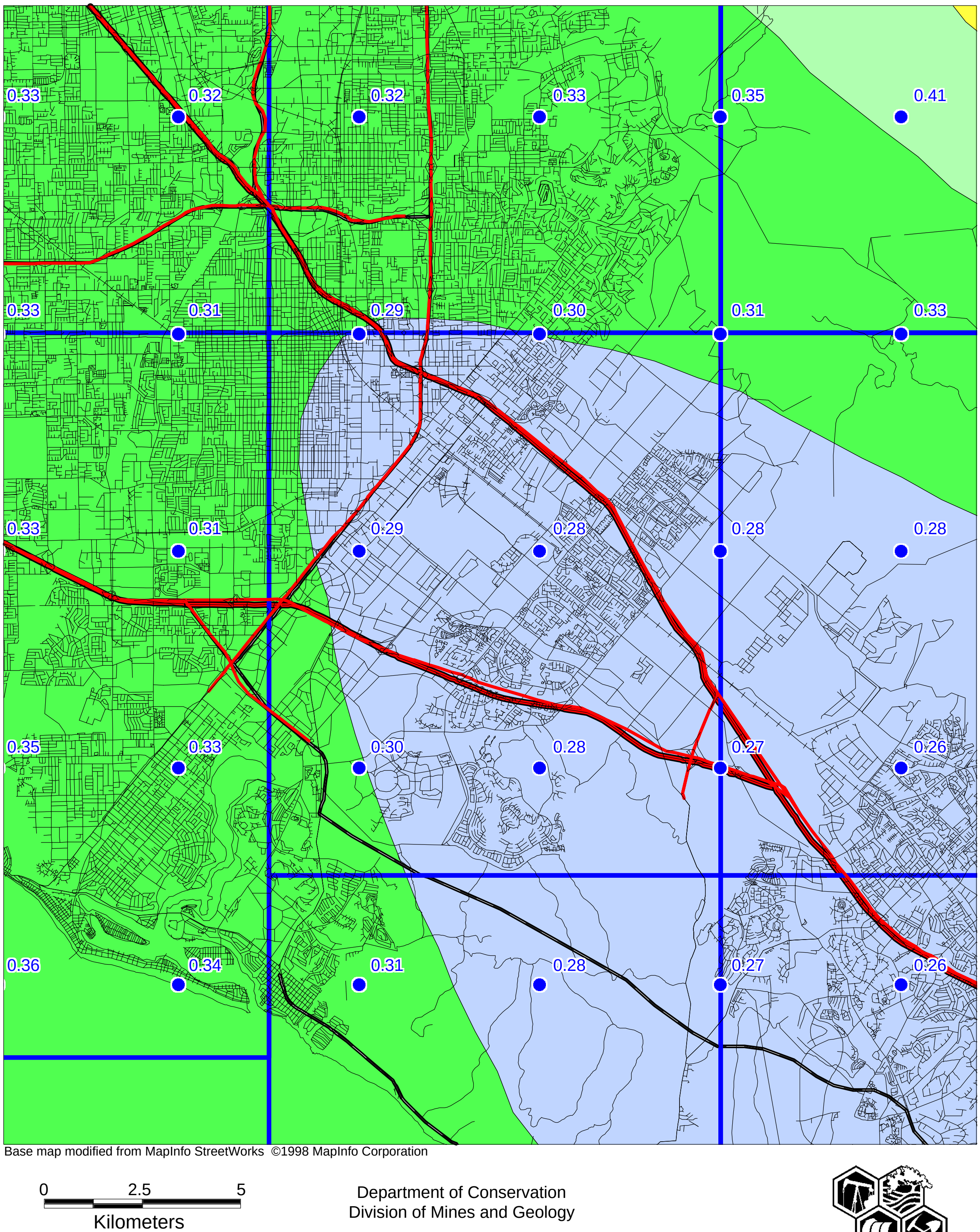
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

TUSTIN 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

Department of Conservation
Division of Mines and Geology

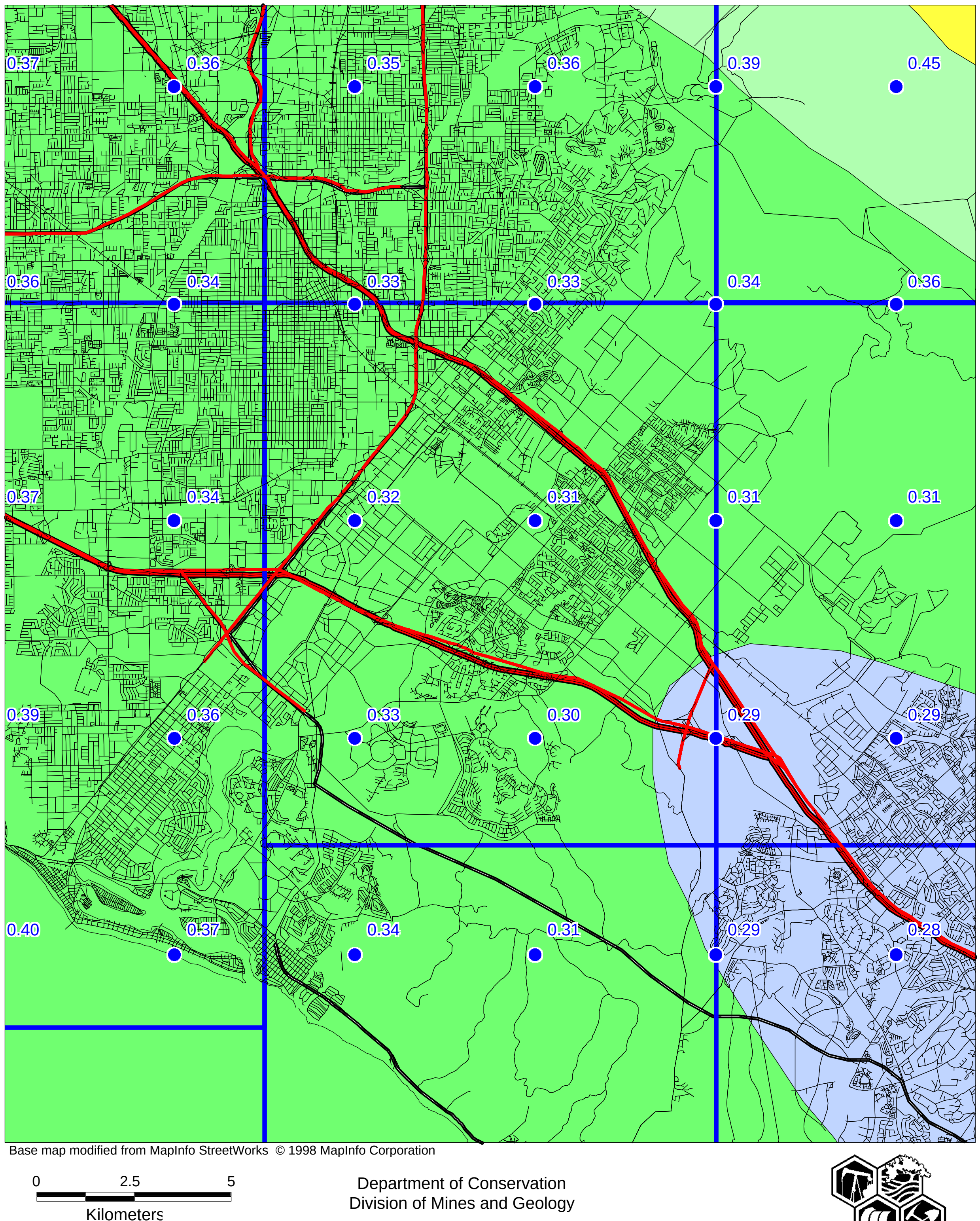
Figure 3.1

TUSTIN 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

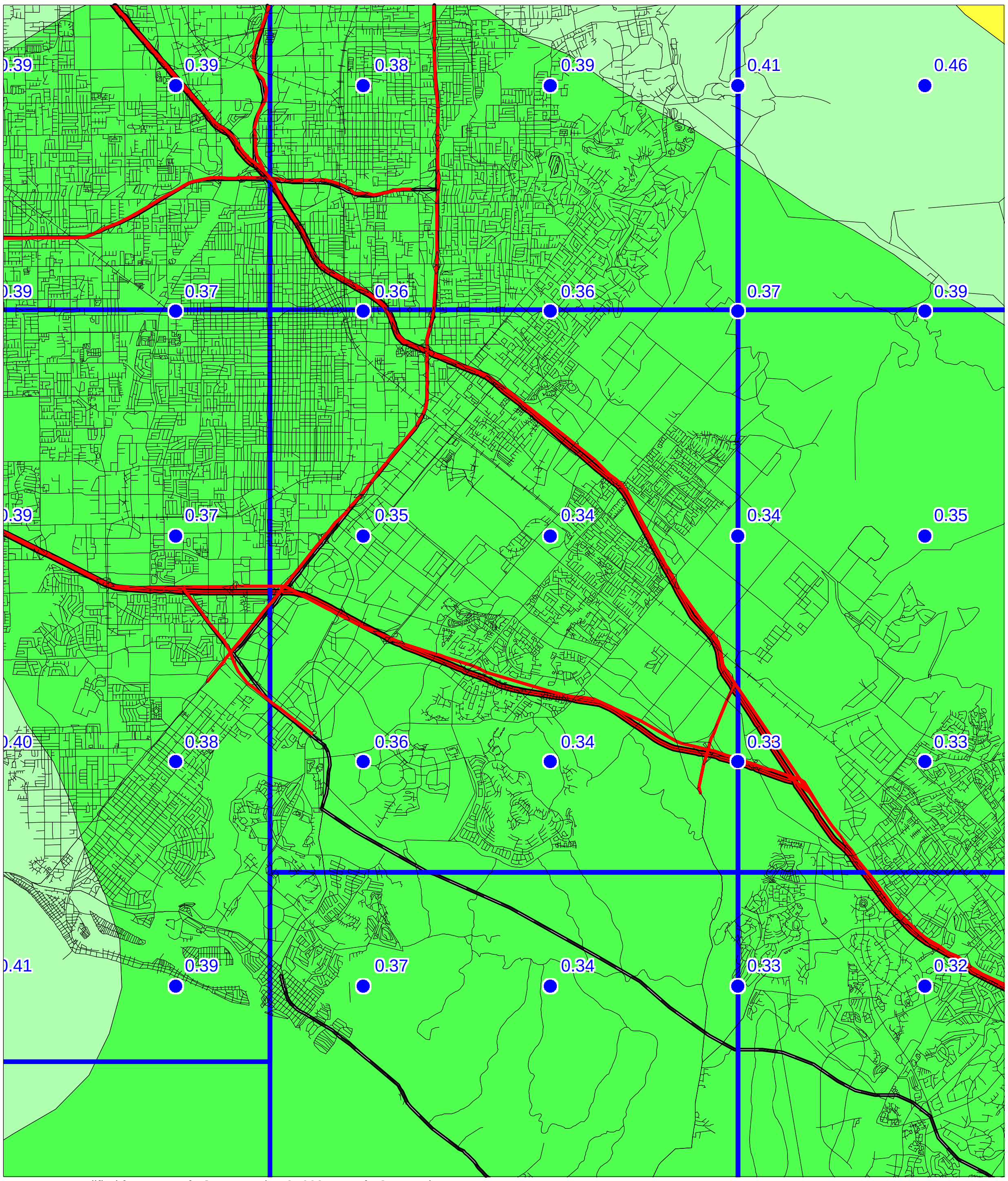
Figure 3.2

TUSTIN 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

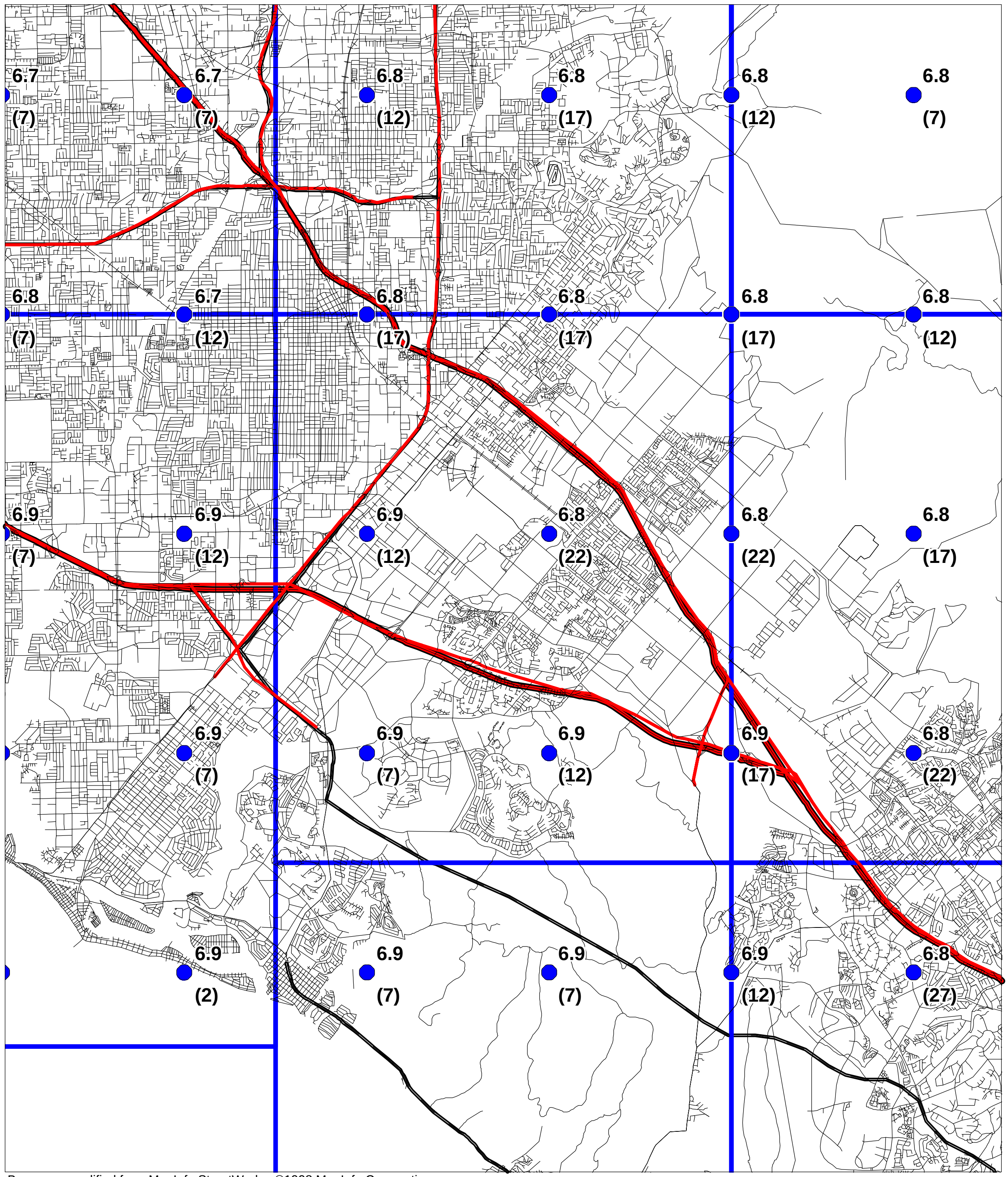
2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual

TUSTIN 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.4

ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.

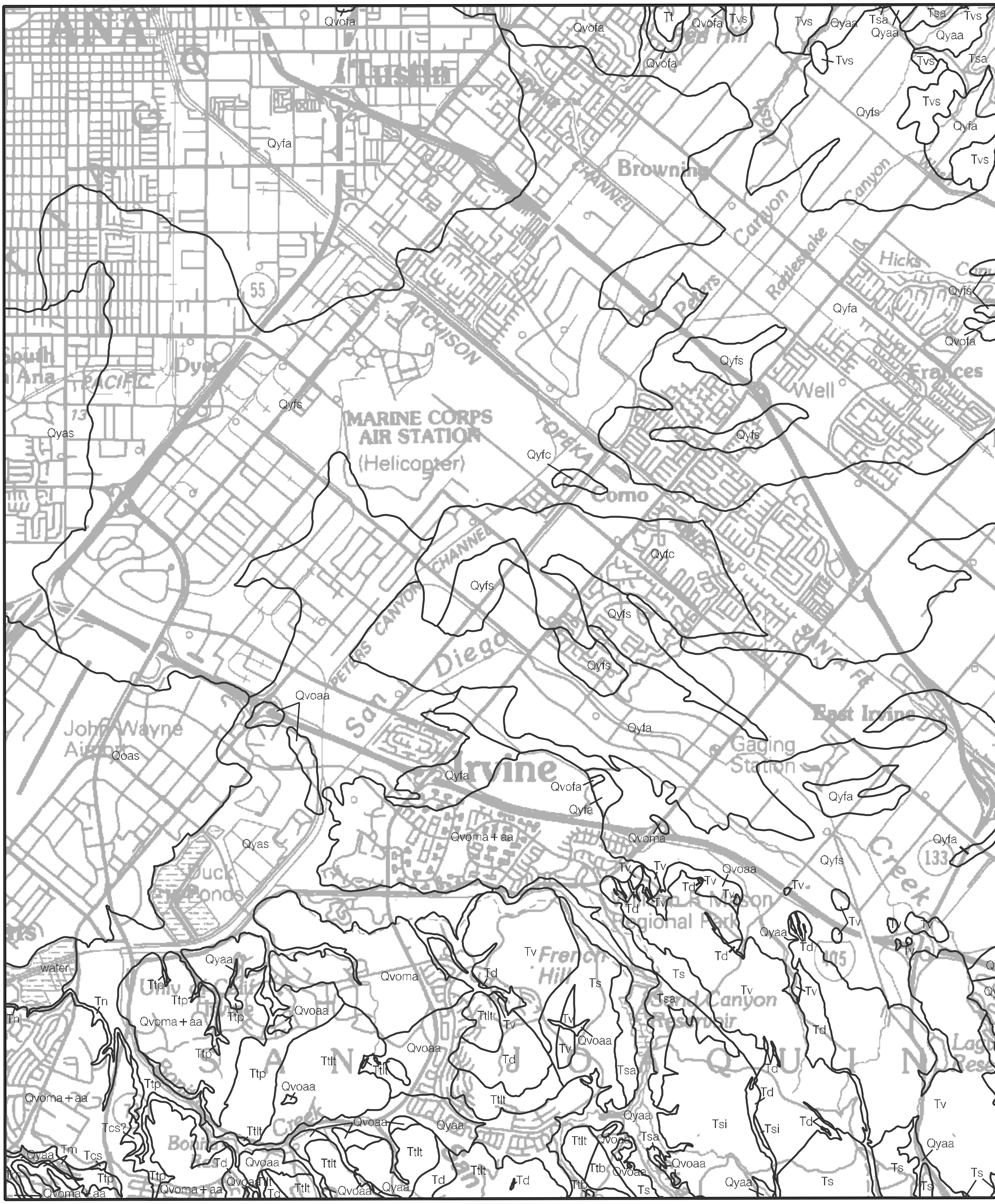
Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 66 p.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



Base map enlarged from U.S.G.S. 30 x 60–minute series

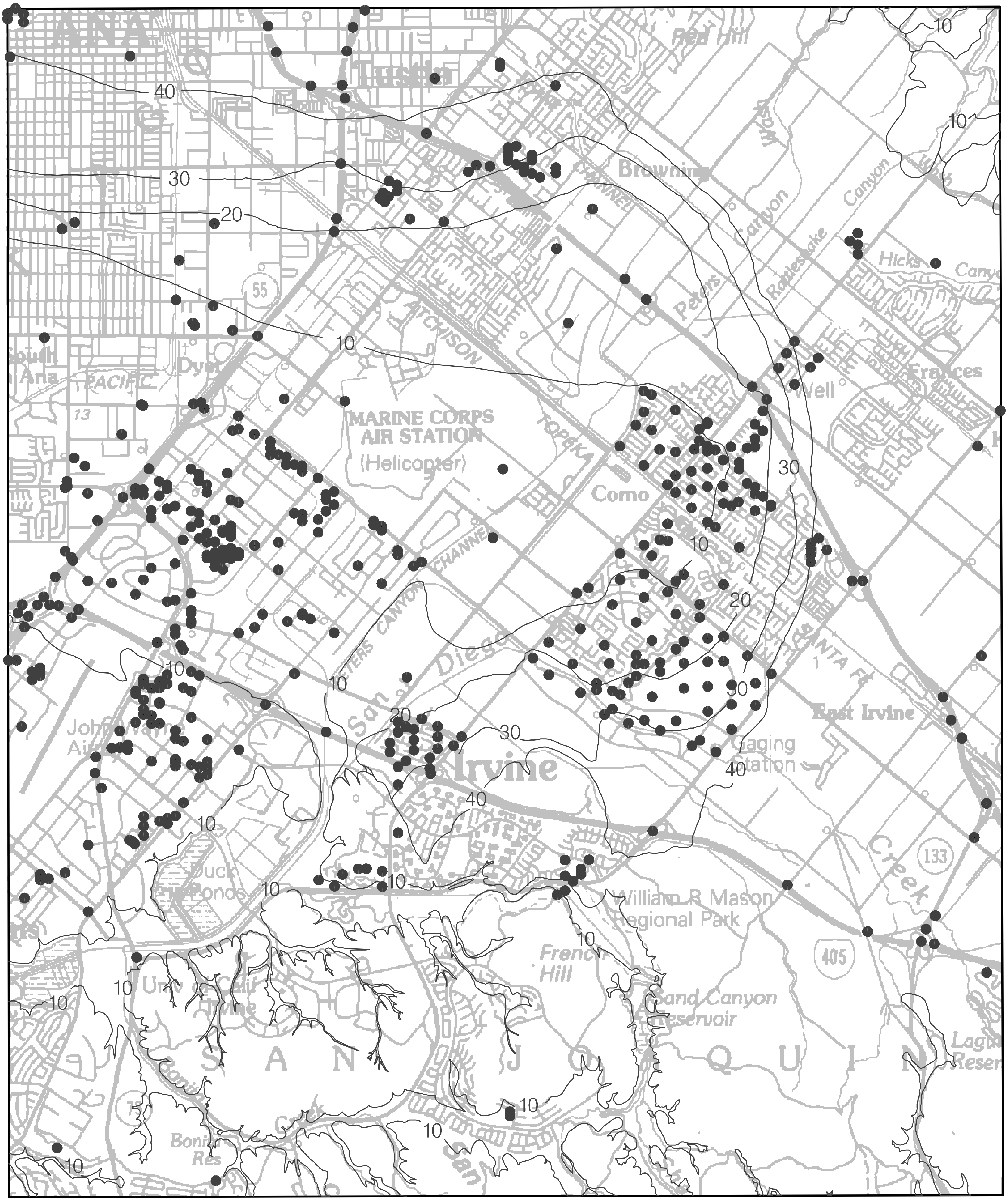
Plate 1.1 Quaternary Geologic Map of the Tustin Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

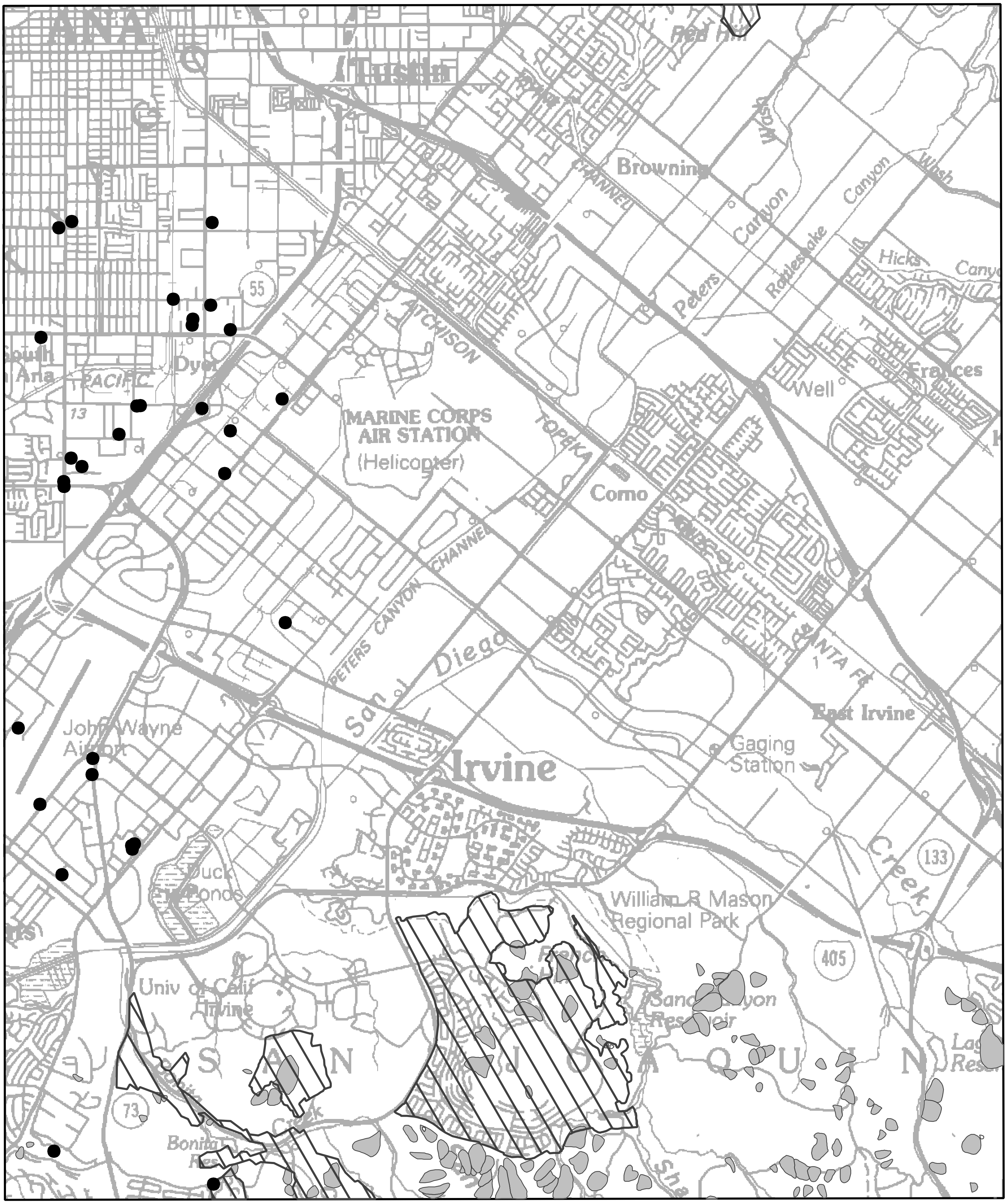
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Tustin Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, Tustin Quadrangle.

● shear test sample location   landslide   areas of significant grading

ONE MILE

SCALE